Dynamic Processes In Underground Pipelines Of Complex Orthogonal Configuration At Different Incidence Angles Of Seismic Effect

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Abstract: Modern problems of seismodynamics of underground pipelines of complex orthogonal configuration under arbitrary seismic effect are considered in the paper. Conducted theoretical and computational-experimental studies solve the problem of assessing the stress-strain state of underground pipelines of complex orthogonal configuration under seismic effect arbitrary directed to the principal axes of the pipeline. Multivariate computations have been carried out for various types of soil and angles of incidence of seismic wave. Dangerous points of maximum stress initiation in underground pipeline systems under the effect of seismic wave propagating at arbitrary angle of attack in space were determined.

Index Terms: underground pipeline, seismic wave, interaction in the “pipe-soil” system, orthogonal configuration, numerical method.

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1 INTRODUCTION

At present, energy transportation is one of the most important sectors of the economy of many developed countries of the world. Undoubtedly, the development of urban areas requires an increase in underground construction [1-5]. As is well known, at present, more than the half of the world's population lives in towns and large cities. From this we can conclude how important are the conditions for providing water, gas, sewage and other underground facilities; this requires a deep theoretical and practical study of their behavior under seismic effects. To date, in domestic and foreign science there exist experimental studies and simplified methods for determining the stress-strain state (SSS) of underground pipelines interacting with surrounding soil under seismic effect [6-14]. Pipeline life support systems consist of straight-line sections connected by joints and orthogonally and non-orthogonally coupled together. A seismic wave initiated during an earthquake affects such a system of pipelines at an arbitrary angle of attack in space. For an underground system of arbitrarily located pipelines with an arbitrary angle of attack of seismic effect in space, it is necessary to develop new computational mathematical models and software for determining the stress-strain state. In this paper, we proposed an approach for determining the stress-strain state of a pipeline exposed to an arbitrarily directed plane seismic wave, the normal vector to the wave front with axis Ox makes an angle α, and β is the angle between the projection of this vector on Oyz plane and the pipeline axis Oy [1-3].

2. METHODS

Consider an orthogonal piping system located on Oxy plane and interacting with surrounding soil. Consider an underground pipeline of a length 180 m and two П-shaped sections on Oxy plane with dimensions 2 m wide and 5 m long (Figure 1). Let the left and right ends of the pipeline be fixed to the ground, and the seismic wave is set as a harmonic function with incidence angles α=45°, β=30°. In general, the task is an unsteady-state spatial task for studying processes in underground pipelines under the action of seismic waves.

***Figure-1**. Section of an underground pipeline of complex orthogonal configuration.*

The system of differential equations for linear sections of underground pipelines, considering their viscoelastic interaction with soil, arbitrary direction of seismic action and corresponding boundary conditions at the ends (2) and initial conditions (3) has the form [2]

$$M\frac{\partial^2 U}{\partial t^2} + A\frac{\partial^2 U}{\partial x^2} + B\frac{\partial U}{\partial x} + CU + D\frac{\partial U}{\partial t} = CU_0 + D\frac{\partial U_0}{\partial t}, \qquad (1)$$

$$F\frac{\partial U}{\partial x} + KU + L\frac{\partial U}{\partial t} = KU_0 + L\frac{\partial U_0}{\partial t}, \qquad (2)$$

$$U = 0, \quad \frac{\partial U}{\partial t} = 0, \text{ at t=0}, \qquad (3)$$

where M, A, B, C, D, F, K, L – are the sixth-order matrices, U – pipeline displacements, U_0 – given ground displacements during an earthquake in the form of seismic waves depending on time and coordinates. As a numerical method for solving the equation of motion (1), taking into account (2) and (3), the finite element method (FEM) in spatial coordinates and the implicit finite difference method (MKR) in time to discretize the problem [15] of the pipeline under arbitrary seismic waves are used. The stresses in the underground pipeline due to axial force N and the combined action of the axial force and the moment of force M under arbitrary action are calculated by the following formulas

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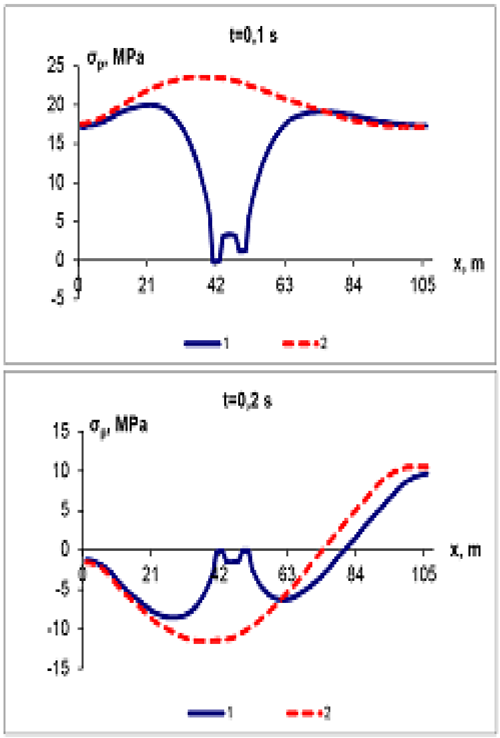
$$\sigma_p = \frac{N}{F}, \tag{4}$$

$$\sigma^{\pm}_{y,z} = \frac{N}{F} \pm \frac{M_{y,z}}{I_{y,z}} \tag{5}$$

The mechanical and geometrical parameters of an underground pipeline and soil are taken as follows: $E=2\cdot10^5$ MPa; $\rho=7.8\cdot10^3$ kg/m^3; $l=180$ m; in a straight-line section $k_x=1.5\cdot10^4$ kN/m^3; $k_{y,z}=3.9\cdot10^4$ kN/m^3; in a complex section $k_x=0.5\cdot10^4$ kN/m^3; $k_{y,z}=1.3\cdot10^4$ kN/m^3; $a_0=0.008$ m; $u_0=a_0\cdot\sin\omega(t-x\cdot\cos\alpha/C_p)\cdot H(t-x\cdot\cos\alpha/C_p)$; $\omega=2\pi/T$; $T=0.3$ s; $C_p=700$ m/s; $u_{0x}=u_0\cdot\cos\alpha$; $u_{0y}=u_0\cdot\sin\alpha\cdot\cos\beta$; $u_{0z}=u_0\cdot\sin\alpha\cdot\sin\beta$; $\mu_{soil}=0.2$; $\mu_{pipe}=0.3$; $D_H=0.5$ m; $D_B=0.49$ m. The maximum value of acceleration of a given wave is 3.50 m/s^2, which corresponds to a 9 point earthquake on the MSK-64 scale.

3 RESULTS AND DISCUSSIONS

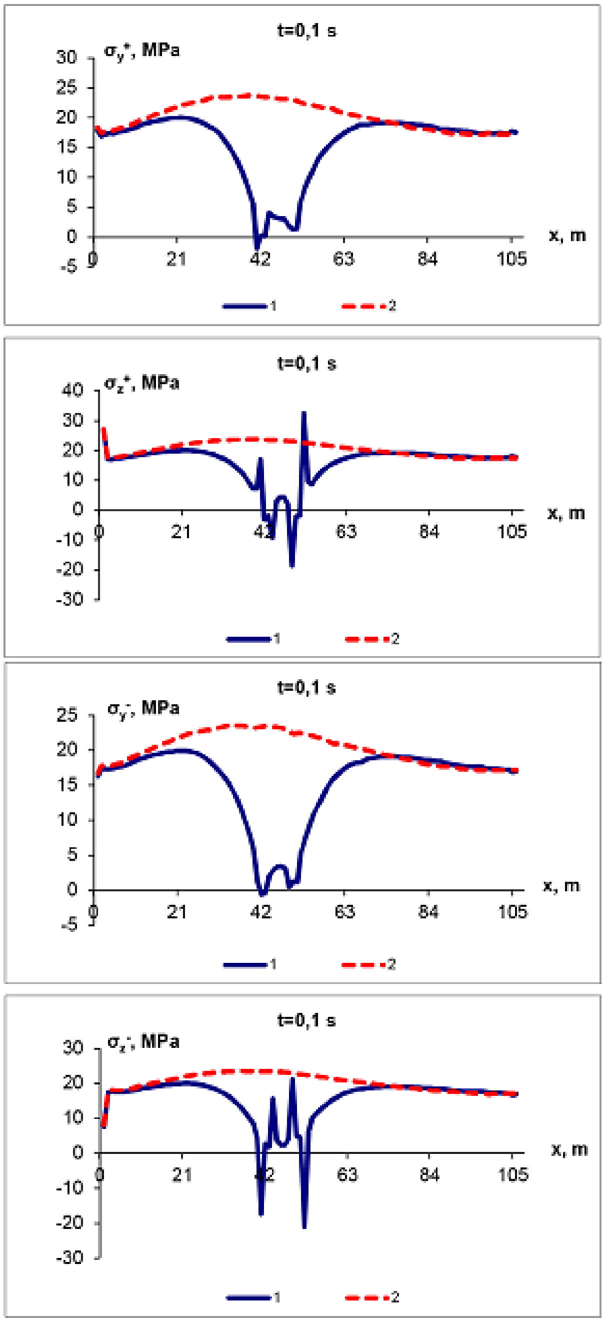
Consider the results of calculations. Figure-2 and Figure-3 show the comparison of stresses in the pipeline in the presence of a П-shaped section and in a straight-line section when exposed to a harmonic wave. The wave initiation and propagation in a straight pipe has its own features. The waveform in a pipeline is determined by the waveform in surrounding soil. Both longitudinal and bending waveforms in the pipeline are similar to the corresponding waveforms in soil [14] if the "apparent" wave propagation velocity in soil is less than the wave propagation velocity in a pipeline. Excitations in a pipeline outside the wave region in soil quickly decay due to the wave energy radiation into surrounding soil.



1–П-shaped pipeline; 2– straight-line pipeline.

***Figure-2**. Changes in axial stress values along the axis of an underground pipeline at specified points of time.*

As seen from Figure-2 the presence of a П-shaped section reduces the axial stresses to a distance of 20–30 m around this section compared to the stresses in a straight-line pipe. However, the total stresses from the axial force and the moment of force in some cases can be greater in the П-shaped section only, when compared to the stresses in a straight-line pipe (Figure-3). The presence of a П-shaped compensating pipe disrupts further wave formation in the pipeline and hence, beyond this section, the wave in the pipeline begins to form anew. Under the action of a harmonic wave, the dynamic process under consideration acquires a stationary mode, starting from the second period of vibrations.



1– П-shaped pipeline; 2 – straight-line pipeline.

***Figure-3**. Changes in total stress values along the axis of an underground pipeline at specified points of time.*

Figures-4–7 show the changes in total stresses from the axial force and the moment of force at various values of angles α and β along the pipeline length at different points of time under the action of a harmonic wave. Here, a complex dynamic process in areas with П-shaped sections is found and the conclusions drawn from Figure-3 are relevant.

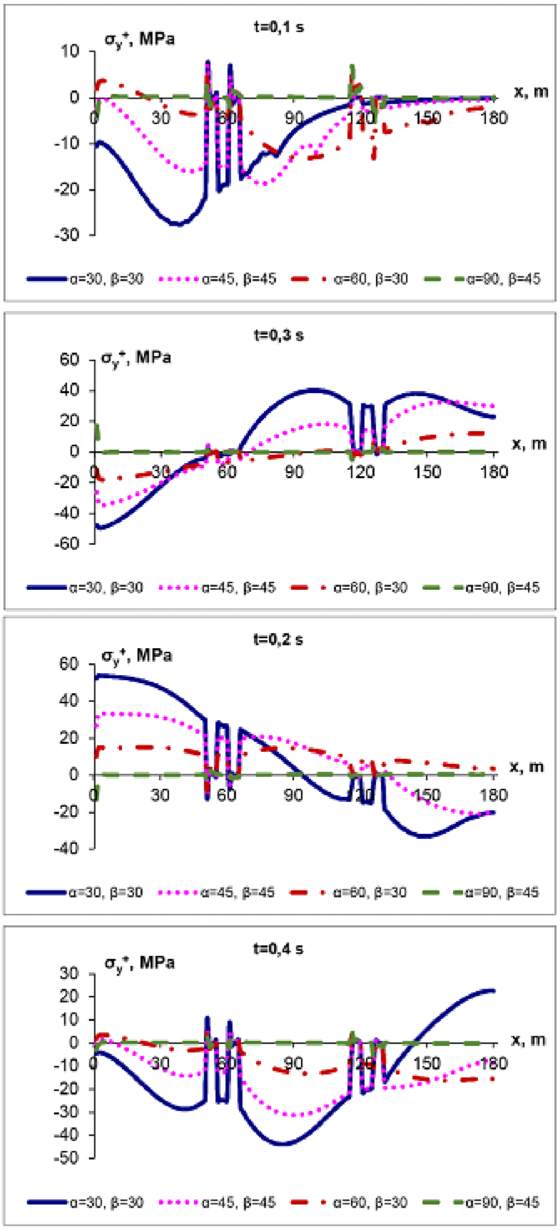


Figure-4. *Changes in total stresses (σ_y^+) along the axis (bending relative to Oy axis) of an underground pipeline at specified points of time for different angles of seismic load.*

At α>0, we can speak of “apparent” wave propagation velocity in soil $C_p^*=C_p/\cos\alpha$, therefore, the wave along the pipeline propagates faster in soil.

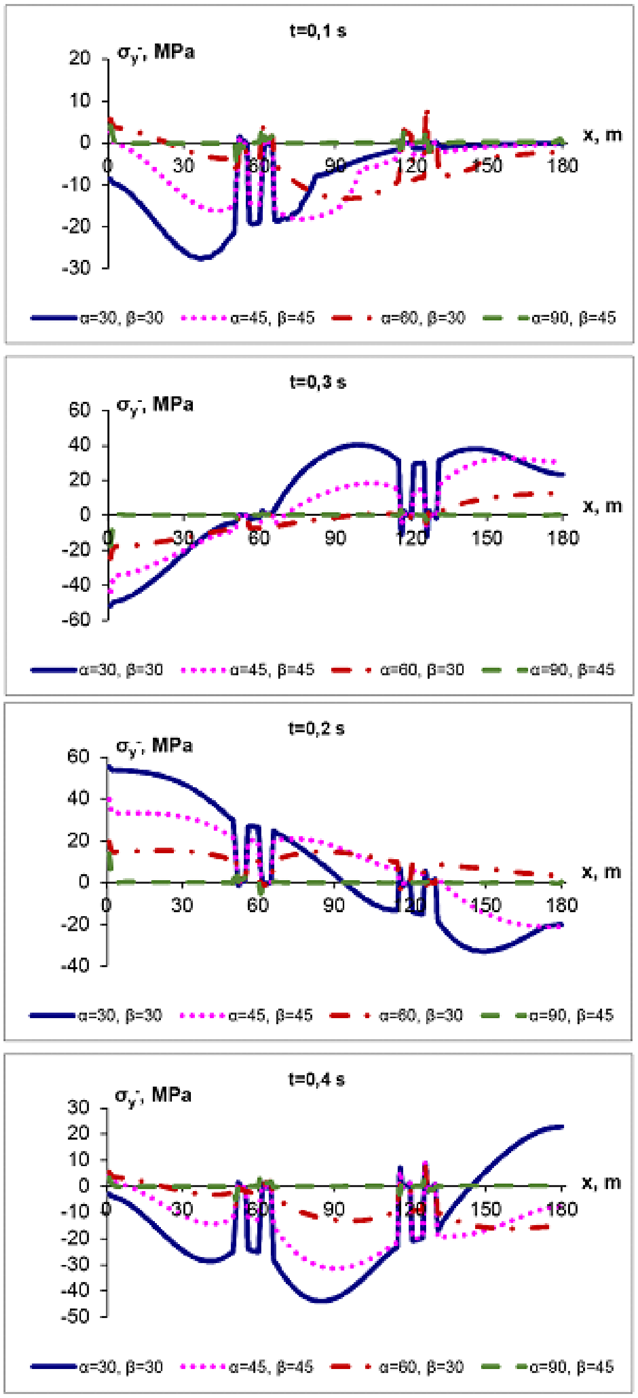


Figure-5. *Changes in total stresses (σ_y^-) along the axis (bending relative to Oy axis) of an underground pipeline at specified points of time for different angles of seismic load.*

At α=0°, the seismic wave mainly causes axial forces in a pipeline, since the length of the П-shaped section is much shorter than the length of seismic wave. At α=30°, the stresses in the pipeline are maximal. At α=90°, the “apparent” wave propagation velocity in soil along the pipeline is infinite, and the wave simultaneously covers the entire length of a pipeline, and, naturally, in this case the stresses in a pipeline are minimal.

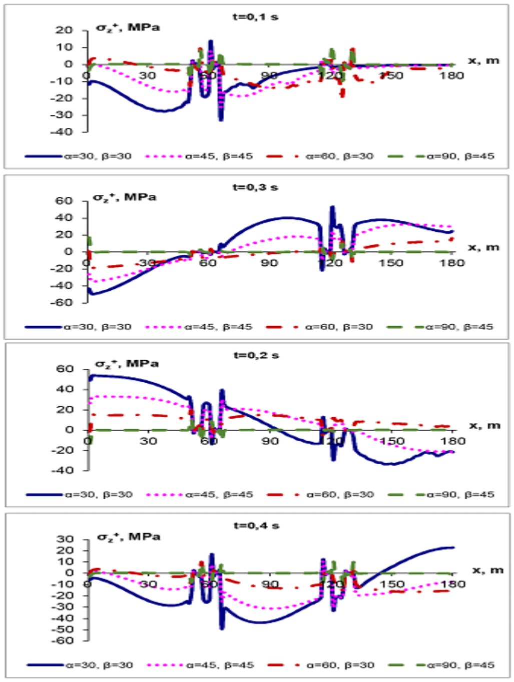


***Figure-6**. Changes in total stresses (σ_z^+) along the axis (bending relative to Oz axis) of an underground pipeline at specified points of time for different angles of seismic load.*

Changing the angle β affects insignificantly the stress level; at β>0, minor torsional moments appear relative to the longitudinal axes of pipelines. Here, the size ratio of the П-shaped section and the seismic wavelength plays a certain role.

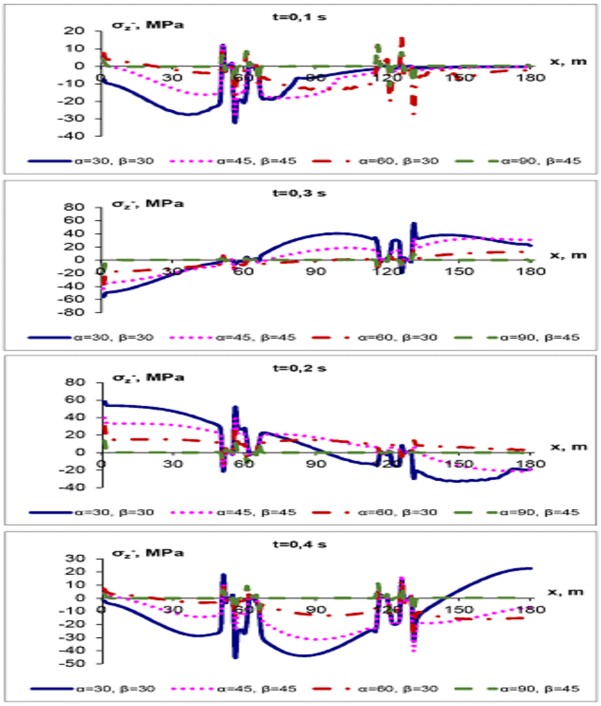


***Figure-7**. Changes in total stresses (σ_z^-) along the axis (bending relative to Oz axis) of an underground pipeline at specified points of time for different angles of seismic load.*

4 CONCLUSIONS

The results obtained when studying dynamic processes in pipeline systems using the developed software product allow us to recommend them for specific calculations and design of underground life support systems under seismic conditions. A number of numerical results were obtained depending on the incidence angle of seismic wave. So, we can conclude that the presence of compensators leads to a decrease in axial stresses near these compensators at a distance of 20-30 m around them. Each specific case has been brought up to numerical values; hazardous points of the maximum stresses occurrence in an underground pipeline under the influence of seismic loads have been determined. The results presented provide a comprehensive analysis of underground pipelines strength during seismic impacts and implement a systematic approach to determining the effect of an earthquake aftermath on the SSS of a pipeline and to planning engineering measures to ensure the safe and reliable operation of an underground pipeline in earthquake-prone areas.

5 REFERENCES

[1]. Rashidov, T.R., Bekmirzaev, D.A. 2015. Seismodynamics of Pipelines Interacting with Soil. Soil Mechanics and Foundation Engineering. 52(3): 149-154.

[2]. Rashidov, T.R., Yuldashev, T., Bekmirzaev, D.A. 2018. Seismodynamics of underground pipelines with arbitrary direction of seismic loading. Soil Mechanics and Foundation Engineering. 55(4): 243-248.

[3]. Bekmirzaev, D.A., Rashidov, T.R. 2015. Mathematical Simulation and Solution of the Problem of Seismo–Dynamics of Underground Pipelines. Journal of Siberian Federal University. Engineering & Technologies. 8: 1046-1055.

[4]. O'Rourke, M., and Liu, X. 1999. Response of Buried Pipelines Subject to Earthquake Effects, Monograph No. 3, MCEER, Univ. at Buffalo, 249 pp.

[5]. Bekmirzaev, D.A., Kishanov, R.U. 2020. Assessment of the Effect of Inertia Forces in Problems of Underground Pipeline Seismodynamics. International Journal of Innovative Technology and Exploring Engineering (IJITEE). 9(3): 500-503.

[6]. Virginia, C., Berardino, D., Nicola, F., Maurizio, G. 2012. Inertial Effects on Finite Length Pipe Seismic Response. Mathematical Problems in Engineering. 2012: 1-14.

[7]. Chian, S.C., Madabhushi, S.P.G. 2012. Effect of buried depth and diameter on uplift of underground structures in liquefied soils. Soil Dynamics and Earthquake Engineering. 41: 181–190.

[8]. Vazouras, P., Karamanos, S.A., Dakoulas, P. 2010. Finite element analysis of buried steel pipelines under strike-slip fault displacements. Soil Dynamics and Earthquake Engineering. 30(11): 1361–1376.

[9]. Saberi, M., Arabzadeh, H., Keshavarz, A. 2011. Numerical Analysis of Buried Pipelines with Right Angle Elbow under Wave Propagation. Procedia Engineering. 14 (2011): 3260–3267.

[10]. Israilov, M.Sh., Mardonov, B., Rashidov, T.R. 2016. Seismodynamics of an underground pipeline in nonideal contact with soil: Effect of sliding on dynamic stresses. Journal of Applied Mechanics and Technical Physics. 57(6): 1126 – 1132.

[11]. Bakhodirov, A.A., Sultanov, K.S. 2014. Waves in a Viscoelastic Bar Surrounded by Soils under Smooth Loading. Mech. Solids. 49(3): 349–359.

[12]. Fayaz, R.R., Himan, H.J & others. 2012. Full-Scale laboratory testing of buried pipelines subjected to permanent ground displacement caused by reverse faulting. The 15th World Conference on Earthquake Engineering. 1-10.

[13]. Li, H., Xue, N., Li, X., Li, Z. 2012. An in-situ Experimental study on buried pipelines with internal pressure subject to a simulated reverse-slip fault movement. The 15th World Conference on Earthquake Engineering. 1-10.

[14]. Mirzaev, I., Bekmirzaev, D.A., Kosimov, E.A. 2019. Formation of Bending Waves in Underground Extended Pipelines under the Action of Seismic Wave. International Journal of Advanced Research in Science, Engineering and Technology. 6(8): 10553-10557.

[15]. Zienkiewicz, O.C., and Morgan K. 2000. Finite elements and approximation. University of Wales, Swansea, United Kingdom, Dover Publications Inc. 352 pp.